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GEOPHYSICS.—*The part played by isostasy in geophysics and geology.*[1]

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It was about a half-century from the time that the idea of isostasy was advanced by Airy and Pratt until there was undertaken a quantitative test of sufficient magnitude to prove or disprove the theory. It was very fortunate that we had in the United States a geodetic problem which had to be solved in the interests of surveying, charting, and mapping. This problem was the placing of the triangulation of the United States on a single spheroid and relating it to a single initial station. The testing of isostasy proved to be an incident in this work.

Prior to the time when the late Dr. John F. Hayford assumed charge of the geodetic work of the U. S. Coast and Geodetic Survey, 27 years ago, there were not sufficient connected triangulation and astronomic data to make possible the placing of the triangulation system of this country, which is the basis for surveys, maps and charts, in its correct relation to the meridian through Greenwich and the plane of the equator. Shortly after Hayford took charge of the geodetic work, the readjustment of the separate arcs of triangulation in a single network was begun. The result of this work was the adoption of what is now called the North American Datum. This datum may be defined as the Clarke spheroid of 1866, a latitude and longitude for the initial triangulation station, Meades Ranch, in central Kansas, and an azimuth from that station to the triangulation station Waldo.

Hayford had available a sufficient number of astronomic stations to make the adjustment of the triangulation to the single datum and he soon learned, from an inspection of the data, that it would be possible

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to make a determination of the shape and size of the earth from the triangulation of the United States alone. In order that this might be done accurately, he had the astronomic latitudes, longitudes and azimuths observed at many more triangulation stations in the country.

It is well known that the method of determining the shape and size of the earth is to compare the values of degrees of latitude and longitude, as derived from astronomic observations, with those determined by triangulation. The difference between the astronomic and geodetic values are due partly to erroneous values for the spheroid used in the triangulation computations and partly to the errors of observations in the triangulation and astronomic work. There is also present in the data an outstanding difference due to the deflection of the vertical or station error which caused much trouble to those who had previously determined the figure of the earth. Hayford, who was familiar with the literature on isostasy, realized that there was a possibility of applying corrections to the astronomic data which might eliminate to a large extent that part of the difference between the astronomic and the geodetic latitudes and longitudes and azimuths which is due to the irregular configuration of the earth's surface and also to the irregular densities in the outer portion of the earth. He assumed, in his computations, various depths to which the irregular densities might extend. These depths varied from zero to 200 miles. He found, as a result of what he called his first investigation, a limiting depth to these irregular densities and, therefore, to the crust, of 113.7 kilometers. A second investigation, in which considerably more data were used, resulted in a derived depth of the crust of 122.2 kilometers. Later an extensive test of isostasy was made by the use of gravity data, and this supplemented and greatly strengthened the conclusions reached from the deflections of the vertical. From the gravity data the best value for the depth of the earth's crust is 95 kilometers. An inspection of Hayford's work indicated that his depth of compensation derived by the use of deflection data in mountain areas only was 97 kilometers. It was thought that a mean of these two values, 96 kilometers, is the best depth and it has been generally adopted by geodesists, although seismologists are inclined to favor a depth of approximately 60 kilometers and many geologists are of the opinion that 60 kilometers most nearly agrees with available geological evidence. We do not know just why there should be a limiting depth to the outer portion of the earth having residual rigidity, but that there is a change in physical characteristics near the 60-mile depth is undoubtedly true.

It was assumed in both the gravity and deflection computations that the compensation of the topography, by deficiency of density under land areas and excess of density under the water areas, is distributed uniformly from the surface to a limiting depth. This, of course, is an artificial assumption, for it is rather difficult to see how there could be any uniformity, except in a most general way, in the distribution of the deficiencies and excesses of density. It is certain that the differences from normal could not start right at the surface of the solid earth as was assumed, nor that they broke off suddenly at a certain depth below sea level. Innumerable assumptions may be made in regard to the distribution of deficiencies and excesses with depth, but the chances are that no two investigators would agree on an assumption. We may however regard the uniform distribution as practically a mean of all of the possible distributions, and, therefore, as probable as any. It has been found, by test computations, that the gravity anomalies can be reduced just about as well by assuming that all of the isostatic compensation is distributed in a thin layer at a depth of about 30 miles below the earth's surface as by having the compensation distributed uniformly. This simply means that no matter what the distribution, we must have the center of gravity of the compensation of approximately 30 miles below sea level. It would be interesting if we could learn the actual distribution of the deficiencies and excesses that balance the topography, for we then might be able to interpret the past history of the earth with more success than is now possible.

The testing of isostasy by the U. S. Coast and Geodetic Survey has been supplemented by that of investigators in other countries. India has taken a leading part and a number of tests have shown that its area is in equilibrium. This has also been found to be true for Spain, Holland, Norway, southern Canada and the Mackenzie Basin. The region around certain islands in the southern Pacific has been found to be in equilibrium. (This Pacific work was made possible by a grant of funds by the Philosophical Society of Washington.) Wherever land areas have been tested the prisms of the crust below have been found to be in isostatic equilibrium.

During the last few years gravity observations of a rather high degree of accuracy have been made at sea on a submarine by the use of a special pendulum apparatus. The instruments were designed and the method devised by Dr. Vening Meinesz of the Dutch Geodetic Commission. It is a long step forward in geodetic work to have a means of

determining gravity at sea and data of great value can now be collected over the oceans by the submarines of many countries. This is a peace-time work for the submarines that should have much value in theoretical science and might, eventually, have a profound influence on industry. Much of the wealth of a nation depends on what is in the earth below its area. We can only discover what is in the earth and how to utilize it by means of geological or geophysical investigations and it is certain that isostasy will be a factor in these endeavors.

It is well known that for the first mile and a half of the earth's crust the temperature increases at the rate of about 50°C. per mile. We do not know what is the temperature gradient lower down, but it is safe to make the assumption that this rate of increase is maintained for some miles below the earth's surface. Much has been written on the heat of the interior of the earth but it is not necessary to do more than touch on this problem here. The pressure on the earth's materials increases with depth to enormous proportions. Is it not possible that the change in the character of the earth's materials from one of residual rigidity to one of practically no rigidity is due to the increased heat and pressure near the depth of compensation, approximately 60 miles below the earth's surface?

Reductions of a number of Dr. Meinesz' gravity stations at sea have been made by the U. S. Coast and Geodetic Survey. There is an indication that gravity over the Atlantic and the Pacific is, on an average, greater than gravity at sea level over the land. After the reduction for topography and compensation has been made for the sea stations there is an outstanding average positive anomaly. This positive anomaly might be due to each of several causes or a combination of two or more of them. First, it might be due to a lack of accurate information as to the configuration of the ocean bottoms for a hundred miles or more around each of the stations. This, however, does not seem to be a very fruitful source for discovering the cause of the anomalies, for a lack of definite information would tend to give both positive and negative anomalies about equal in number. The lack of definite suboceanic topographic data would be accidental in its effect.

The second cause for the positive anomalies might be an actual departure of crustal prisms beneath the ocean from the perfect isostatic condition. This, however, does not seem to be a very probable cause. The earth's crust has been formed for a billion years or more and the central portions of the ocean basins have been less disturbed by erosion and sedimentation than have the land areas; therefore, the

crust beneath the central parts of the ocean is likely to be more nearly in equilibrium than elsewhere. The prisms of the crust under the oceans have had sufficient time to bring about complete isostatic adjustment among themselves and with respect to continental areas.

The third cause for the positive anomalies may be the irregularities in the geoid surface. Over the oceans, with isostasy practically perfect everywhere, the geoid surface should be and probably is closer to the center of the earth than are points at sea level on land areas in the same latitudes. In a given latitude the value of gravity increases toward the center of the earth down to a certain distance below sea level. On the other hand it decreases with elevation above the surface of the earth. A change in elevation of ten feet makes the computed value of gravity one part in a million greater or smaller. Gravity values are reduced to the geoid because we do not have sufficient data to determine the relation at any particular point between geoidal and spheroidal surfaces. A computation was recently made at the office of the U. S. Coast and Geodetic Survey by C. H. Swick which showed that, in the middle Atlantic the geoid is approximately 8 meters below the spheroid or to put it in another way, using the spheroid as a datum, the geoid is 25 meters lower than at a certain point in the Appalachian mountains in South Carolina to which the computation was referred. Such a difference in the elevation of the geoidal surface in relation to the spheroid should make a difference in the value of gravity of about 8 parts in a million. The effect on gravity of the depression of the geoid over the ocean areas would seem to be systematic and the average gravity anomalies over the oceans should, for any large area and large number of stations, tend more to be positive than the average anomalies over large land areas.

The factors in the gravity formula by means of which we obtain the gravity at sea level at any latitude are based on the values of gravity observed over continental areas. Necessarily, since in this area the geoid is above the spheroid, the values of gravity are too small. It would seem that a gravity formula to be used for both land areas and oceans should be based on observed values well distributed over land and water. Then, if we knew the deviation of the geoidal from the spheroidal surface, we could apply negative corrections to the computed values over the land areas and positive corrections to the values over ocean areas. Then, the resulting mean anomalies with regard to sign would be approximately zero for any large group of stations, whether on land or water.

The question of the reduction of gravity stations to the geoidal surface rather than to the spheroidal is a matter that needs to be investigated further with a view to learning just what the gravity anomalies at stations at sea, which tend to be positive, may mean in terms of isostasy.

There is another cause for outstanding anomalies at sea just as for large anomalies on land; that is the presence of material that is abnormally heavy or light in density close to the gravity station, both horizontally and vertically.

It would seem from the results of gravity observations taken at sea that isostasy in the crust under the oceans is approximately as complete as under the land. After all corrections have been applied to the computed values, including the reduction to the spheroidal surface, the remaining anomalies would on an average be quite small as compared with the effect of a deficiency of crustal material equal to the difference between the mass of ocean waters and a mass of surface rock of equal volume.

It seems necessary to conclude from the proof of isostasy that the isostatic adjustment or transfer of material from the base of a prism of the crust that is being depressed by sediments to the base of a prism of the crust that is undergoing erosion must take place below the crustal material. The material of the crust itself has residual rigidity and maintains its form for geological time. It is, therefore, too strong to permit of horizontal flow as a result of disturbance of the isostatic equilibrium. Besides, this material has apparently maintained through a long period of geological time, different densities in columns extending approximately 60 miles below sea level. There is a stress difference from high areas towards the low areas of the earth's surface until the depth of compensation has been reached where the stress difference is practically zero. Therefore there could not be in the upper part of the crust any horizontal movement of material from the sedimented area towards the area that is being eroded.

The principle of isostasy is a proof also that the earth's crust is exceedingly weak. No definite dimensions can be given to the mass of material that can be held up by the earth's crust without isostatic adjustment but a test has been made which throws some light on this subject. Of the more than 300 stations of the United States, 42 having elevations of 1000 meters or more were selected for the test. For each of the stations, corrections were applied for the topography of the world and for the compensation of all of this topography except for a disk directly under the station extending horizontally to a dis-

tance of 17.9 miles. The result of ignoring that compensation was to make all of the stations have negative anomalies, except 4, and the average anomalies with and without regard to sign became −0.037 and 0.040 dyne.

This, it seems, is an indication that we cannot ignore in our gravity reductions the compensation of even such small amounts of topography without having the anomalies bear a definite relation to the elevation of the station. A second test was made with these stations by ignoring the compensation of the disk of topography extending to a distance of 36.5 miles in all directions from the station. In this case all of the anomalies except one became negative and the mean values, with and without regard to sign, became −0.072 and 0.072. It is certain that a disk as large as 1000 meters in thickness and 36.5 miles in radius is largely compensated and it is probable from the two tests that a disk much smaller than 1000 meters in thickness and 17.9 miles in radius does not escape compensation entirely. These tests seem to give some idea of the masses which the earth's crust cannot withstand as extra loads.

Since the earth's crust is so weak as not to withstand the loading and unloading caused by sedimentation and erosion, we must conclude that some of the geological theories that are based on the idea of a very rigid crust, carrying horizontal thrusts for hundreds and even thousands of miles, must be modified or abandoned. In this particular, it would seem that isostasy has its most important bearing. Isostasy in itself is not an active agency; it is a condition of rest and its proof leads to the logical conclusion of a very weak crust and thus restricts the field within which hypotheses and theories may be formulated to account for surface changes.

There are two ideas of isostasy, one advanced by Airy and the other by Pratt. The Airy idea postulates a rather uniform density of crustal material or at least a density that varies the same along all radii. That view requires a greater thickness of crustal material under continental and island areas than under water areas. This theory seems logical until we inquire into the cause of mountain uplift and of the formation of synclinoria. The advocates of the Airy idea claim that the thickening of the crust is due to a crushing and distorting of crustal material beneath areas which have undergone heavy sedimentation. They hold that the crust beneath such areas is weaker than in other places. The horizontal forces causing that crushing are supposed to have their origin either in the collapsing of the non-cooling crust on

a cooling interior, or to an expansion of the crust due to radio-activity without any change occurring in the volume of the nucleus, or to a collapsing and buckling of the crust on a nucleus which is being compressed by the overloading of the crustal material. Any one of these processes may be going on but it is quite certain that, should there be great horizontal forces carried through crustal material, the deepest parts of the ocean would be the ones to buckle up rather than areas of erosion, the surfaces of which are close to sea level. On the Airy hypothesis the crustal material under the oceans must be very much thinner than under continental areas and therefore the first to yield.

The Pratt hypothesis calls for a uniform depth of crust with material of different densities in the prisms under surfaces of different elevations. If we assume normal densities for the crustal material under the coastal plains then we must assume a lighter material under the plateaus and mountain areas of the continent and a heavier material under the oceans. One objection to the Pratt hypothesis is that changes in density of crustal material, greater than those caused by ordinary thermal expansion, must be taking place when an area once at or close to sea level is thrust upward into a plateau or a mountain system. If the mountains are three miles high on an average, which is approximately that of the Himalayas, the Pratt hypothesis requires a 5% increase in volume and decrease in density in the prisms of the crust below. This is on the assumption that the crust extends to a depth of 60 miles below sea level. On the other hand, if a synclinorium is formed where previously there was an area of uplift and erosion, we must assume on the Pratt idea a greater contraction of the prism of the crust beneath, than could be caused by normal thermal contraction, and a decrease in volume. The usual thermal expansion or contraction is not enough to account for the major uplifts and depressions.

The Airy hypothesis and also many of the old hypotheses which are based on a collapsing crust, must seek some interior cause of the major movements of the earth's surface. With the Pratt hypothesis, on the other hand, erosion and sedimentation seem to be all that is needed to start the sequence of events which change the surface configuration.

An enormous quantity of water has fallen to the earth's surface during the geological period. The average annual rate of rainfall is about 30 inches for the land areas of the world. At that rate there would be approximately a mile of rain in 2000 years or somewhat more than a half million miles during the sedimentary age which is generally supposed to be about 1½ billion years long.

The rate of erosion for the United States as determined by the U. S. Geological Survey is equivalent to one foot of material over our 3,000,000 square miles of area in 9000 years. At that rate, there would be a mile of erosion in about 45,000,000 years. The sedimentary age is more than 30 times that long. This indicates what a tremendous amount of work has been done on the earth's surface in transferring material from one place to another. The amount of erosion in any one area would not of course be as much as 30 miles in thickness, due to the fact that an area is base leveled long before any such amount of material can be carried away. On an average, however, erosion may have aggregated something like 30 miles or more during the sedimentary age. Of course, some areas might have been above sea level undergoing erosion at one part of the age and during another part might have been below sea level receiving sedimentation. For this reason the erosion from any one area during the entire sedimentary age might have been only a fraction of the total amount of erosion which could have taken place in an area continuously exposed to approximately the same conditions now found in the United States.

Nearly all of the sediments derived from a continent go to shoal water and are deposited within about 100 miles of the shore. Only a small part goes beyond that limit. These sediments are deposited in a most irregular way. The mouth of any particular river may wander along the shore or change its position as the Yellow River did in 1852, shifting from the south to the north side of the Shantung Peninsula. The sediments deposited by a river will be deeper in some places than in others and the chances are that they will be the deepest not very far off the general coast line of the continent. Farther out to sea, they will gradually thin out. If the sediments are being deposited in an inland sea they will be thickest close to the shores of the sea. All mountain ranges seem to have been uplifted in areas which have previously been subjected to very heavy sedimentation. There seems to be a direct connection between sedimentation and mountain uplift.

As material is carried from elevated regions and deposited in lower ones, the isostatic balance is disturbed. The weight of the sediments depresses the crust beneath them, and the prisms undergoing erosion become lighter than normal. The result is that the crust in the area of sedimentation tends to sink and to force subcrustal material into crustal space, finally pushing up the lightened erosion prism. Eventually a balance is restored between the crust beneath the sedimentary area and the crust under the erosion area by movement of subcrustal material.

There is no such thing as a transfer of subcrustal material from below the crust where sedimentation is occurring to the space below the crust undergoing erosion. There is merely a pushing aside of crustal material as the sediments depress prisms and the result is a movement of subcrustal material all the way back to the area of erosion. The motion is similar to that which would occur in a pail of water, in which wooden blocks are floating, if one block is increased in mass and the other decreased. The water does not flow from one block to another but the whole liquid mass is readjusted. How far below the crust the distortion of subcrustal material may occur in the restoration of the isostatic balance is not known. It may be 10, 100 or even 1000 miles but probably the thickness of subcrustal material affected is not excessive.

If an area undergoing erosion should lose 1000 feet from the surface there will not be that much lowering of the area, for there will have occurred an influx of subcrustal material below the base of the prism to restore the isostatic equilibrium of the prism affected. The amount of lowering will depend on the relative densities of subcrustal and crustal material. If the difference in density is 10% then the surface would be lowered only 100 feet by the erosion of 1000 feet of material. It is thus seen that many times as much material can be eroded from an uplifted area before base leveling has been accomplished as there was in the original uplift. Of course uplift occurs gradually and as soon as an area begins to increase its elevation above the surrounding regions, erosion commences, so the mass of the original uplift is more or less a hypothetical quantity.

When an elevated area has been base leveled the source of sedimentation has been shut off and there is quiescence in the erosion and sedimentary areas. In a later geological period the former erosion area becomes a basin in which sediments are deposited. On the other hand, the former sedimentary area is uplifted and a mountain system or a plateau is formed from which erosion begins. There is thus a sort of oscillation between the uplifted and downwarped areas. Such areas have, no doubt, changed positions several times during the sedimentary age and will continue such changes in the future.

While there is much sedimentation in lakes and valleys, a great part of the material washed down from great elevation is carried to sea and deposited near the shores. Eventually a belt of sedimentation 100 miles or more in width is extended along the whole waterfront of a continent. Later this material is raised up into a plateau or mountain

system and then erosion from it occurs. Part of the eroded material will work inland, possibly to the regions from which the sediments came, but much of it—probably at least half—is carried out to sea. Thus there is ever a tendency for the continental area to encroach on the ocean area. The process might be exceedingly slow and still be considerable in amount during a long geological period. We have no available evidence to show just what were the original limits of the continental areas. In the continental areas should probably be included areas along the shores out to the edges of the continental shelves. The continental areas are much larger when thus considered. The sediments that are carried to sea force subcrustal material back towards the areas of erosion. As the density of sediments must be from 10% to 20% less than that of the subcrustal material the thickness of the sediments must be that much greater than the thickness of the subcrustal matter displaced and a gradual filling up of the ocean areas must be taking place.

It seems certain that the earth's surface was very irregular before the beginning of the sedimentary age. This is indicated by the heavy elements found in greater percentages in the igneous rocks on the ocean islands than in the igneous rocks on continents. The specific volumes of these igneous rocks for land areas are greater than for the lavas under the ocean areas. It seems probable that the earth's crust was in equilibrium before the beginning of sedimentation and, if so, then owing to the variation in the specific densities of the igneous rocks composing the crust, there should have been some areas standing at higher elevations than others. When water began to fall to the earth, it collected in the low areas to form oceans and inland seas. The weight of the water then disturbed the isostatic equilibrium of the crust and caused a readjustment by the movement of subcrustal material from below the water areas towards the land areas.

I am assuming that, prior to the sedimentary age, the earth's surface was too hot to permit water to fall on it and remain there. This may not have been the real condition of affairs, for water may already have been on the earth with the atmospheric conditions such that there were no evaporation and precipitation to cause water to run over the land areas. In any event there was a time when rain began to fall. Without running water over land areas there could have been no erosion and sedimentation. It would be rather difficult to see how the processes which have been going on to cause the irregularities in the earth's surface could begin to operate if the surface were perfectly

level at the beginning of the sedimentary age. The earth must have become quite cold, if it were ever in a molten state, by the time that the sedimentary age began, and any instability, due to internal causes, would certainly have been eliminated before the earth had cooled to the point where water could remain on its surface.

Owing to the fact that the earth's crust is now in isostatic equilibrium, and that it probably has been so for all of the sedimentary age and even for a long time prior to the beginning of that age, we must conclude that the strength of the crustal material is very low. It will yield or break under the gravitational forces resulting from the accumulation of sediments or the unloading of an area by erosion. A crust so weak as to remain in isostatic equilibrium is not competent to carry thrusts through great distances such as are required in the collapse hypothesis. Many who held to that hypothesis prior to the establishment of isostasy, now believe in what is generally called the "roots of mountains" theory which, in effect, is the idea of isostasy as first advanced by Airy.

In order that crustal material may extend into subcrustal space in the form of roots to balance the masses above sea level, it would have to be extremely weak under the uplifted areas. If the normal thickness of the crust were 50 miles and if the difference in density between the lower crustal and the subcrustal matter is 15 per cent then the extension of the crust into subcrustal space under an uplifted area having an average elevation of two miles would be of the order of 15 miles. The crustal material under the elevated region would have been tremendously distorted to have a 50-mile thickness increased to approximately 70 miles. Even though there were a weak place in the crust, under the sediments which had been laid down prior to the uplift, this part of the crust would have been thickened materially shortly after the uplift began. Then, instead of a thickness less than normal, there would be one greater than normal, and the result of continued distorting of the crustal material to the sides of the area affected would be to buckle up the crust off to the sides of the area which had previously been one of sedimentation. Of course, the beginning of the movement of uplift and of depression of a root might have heated up the prism of the crust and thus made it weaker than normal but it seems to me that the mechanics of the "roots of mountains" theory are not very sound.

There is another weakness in the roots theory. The material of the roots which was weak enough to be crushed, distorted and pushed

down into subcrustal space against the hydrostatic pressure of the subcrustal material, would seem to be too weak to maintain its new position for a long geological time against that hydrostatic pressure. Material cannot be both strong and weak and, if the roots can be formed by the weakness of the crustal material, they cannot be strong enough to maintain themselves against the gravitational forces exerted against them.

The proof of isostasy and the consequent weakness of crustal material force us to the conclusion that the major changes in surface elevation must be due to a change in volume of the crustal material directly below the affected areas. The isostatic investigations have shown that the most probable depth to which the crustal material extends is about 60 miles. The temperature gradient found from measurements of temperatures in wells and mines is approximately 50°C. per mile. The gradient varies greatly from place to place, but this is a fair average. We may assume then a temperature gradient of about 1°C. per 100 feet. If the earth were maintained in isostatic equilibrium to a very high degree of perfection, then as sediments were deposited along the coast or in lakes or valleys, the crust would sink down under the added weight. It is not known just how thick the sedimentary beds must be before there is an isostatic yielding of the crust below but if, say, a hundred feet of sediments causes an adjustment, then each element of the crust below would be pushed down nearly one hundred feet into regions which are about 1° hotter than the space they formerly occupied. While sedimentation progresses at a rather slow rate yet the conduction of heat through rock is supposed to be even slower.

The normal thermal expansion of a prism of rock 60 miles in length per one degree Centigrade is about 10 feet. The coefficient of expansion on which this calculation is based is that of marble. For a thousand feet of sediments the change in temperature due to the isostatic yielding of the crust might result in a subsequent uplift of 100 feet. It is believed that many of the small vertical oscillations of the surface of the earth have been caused by the thermal expansion and contraction of the crustal material after it was pushed down under sediments to hotter regions or raised to colder regions by isostatic adjustment following erosion.

The maximum thickness of sedimentary beds for any one period is generally believed to be about eight miles, approximately 40,000 feet. The expansion of the crustal material depressed eight miles due to

thermal change would be about 4000 feet. That is, the surface would be raised approximately that amount when the depressed crustal material had taken on the temperature normal to the new position. But 4000 feet is a small elevation, as compared with what we have in many mountain regions. The Himalayas have a maximum elevation of about 29,000 feet while the average elevation is close to three miles. The Andes have an average elevation of about three miles. We therefore must look for some cause other than thermal contraction and expansion of crustal material to cause surface changes. By a process of elimination we are forced to conclude that a change of density and volume is brought about by chemical or physical processes in addition to that caused by thermal expansion and contraction. Just how this occurs it is impossible to say, but there are numerous cases of two minerals having exactly the same chemical composition but different volumes and densities, a notable example being diamonds and graphite. Both are pure carbon, but the diamond has a density of 3.52 and the graphite only 2.25. The difference is about 36% of the density of the diamond. It may be that there is some rearrangement of the elements as a result of changes of temperature and pressure which would cause a change of density of 3% in the prism of crustal material, and that is sufficient to raise the surface as much as two miles.

We have no proof that expansion and contraction actually take place in the earth's crust but a careful consideration of the mechanics of the earth seems to make these the most probable causes of surface changes. Opposition to this explanation of surface changes has been raised by a number of students of the earth because of their difficulty in explaining on this basis the great horizontal movements which have occurred in the material near the earth's surface. Undoubtedly there have been extensive horizontal movements but the writer maintains that these can be explained more easily on the theory that they are incidental to the vertical uplift rather than that they are the major movements and that the vertical movements are incidental. In practically all cases where a horizontal movement has been detected in exposed strata, the thickness of the strata involved was small; probably one or two miles is about the maximum thickness of material that has been overthrust for any considerable distance. Usually the thickness of material involved in the overthrust is a half mile or less and in some cases only a few hundred feet. It is difficult to see how a thin veneer of stratified rock could be moved horizontally for the many miles that some have estimated the movement to be. The moving

material must overcome frictional and shearing resistances and if the uplift is due to the action of regional forces the overthrust material must be pushed uphill for it is in this direction that the movement would occur according to the collapse hypothesis.

On the collapse hypothesis the crust that is weak enough to be distorted by the action of horizontal forces carried through long distances must be strong enough to push up a mountain system and to force down into subcrustal space sufficient material to form a root that will support the mass which is above sea level. These horizontal forces, presumably, would be acting through the whole crust rather than merely in the outer layers. I cannot conceive of blocks of material a mile or two in thickness being pushed overland distances of 10, 20 or more miles as seems to be required to explain certain cases of overthrusting. Of course, it is difficult to explain an overthrust of 50 miles on any hypothesis and the isostatist has little or nothing to suggest, except that the field evidence regarding the overthrusting and the extent of horizontal movements in general may have been somewhat misinterpreted. One is likely to see in data those things which support the views that are considered authentic. It is my belief that as much evidence, probably more, could be collected in the field in favor of the vertical uplift theory as may be obtained in support of the view that the horizontal movement is the predominating one.

It is probable that the direction of the overthrust and of much of the horizontal movement of material is from the center of the uplifted mass outward towards its edges. If this should be found to be true then the Pratt theory of isostasy would be much strengthened.

In Daly's recent book, The Mobile Earth, he mentions a block of material resting on the plains of Montana many miles to the eastward of the uplifted area from which it came. That is a clear indication that the overthrust was from the uplifted regions towards the low areas to the sides. When the direction of overthrusts has been discovered, we shall be able to make greater progress in the solution of the problem as to how the uplift occurs.

A Pratt isostatist naturally leans towards the idea of a very weak crust with expansion and contraction of crustal material as the major causes of surface changes in elevation. A belief in the Pratt isostasy leads one to think that earthquakes are the result of four major processes. An earthquake is generally accepted as being due to the breaking of rock. This rock must be within the crustal space for the subcrustal material is too plastic to break but instead it yields and

conforms to changes without rupture. The crustal material itself must vary somewhat in plasticity as its lower limit is approached. The lower crustal material is under a tremendous load and movement in the lower half of the crust would be somewhat plastic with very little breaking of material. Seismologists have not yet determined with any degree of definiteness the depths at which the earthquakes occur, but the late Prof. Omori of Japan, who was recognized as one of the foremost seismologists of all time, claimed that he had not found any earthquake focus lower than 27 kilometers. I do not know whether his methods of determining the depth were adequate to secure exactness but his depths are very acceptable to the Pratt isostasists.

The four major causes of earthquakes would seem to be:

1st. The breaking of crustal material caused by the weight of sediments.

2nd. The breaking of rock as the crustal material is pushed up under an area of erosion to restore the isostatic balance.

3rd. The breaking of the rocks as the result of the expansion of the crustal material under an area which had previously undergone heavy sedimentation.

4th. The breaking of rock caused by the contraction of crustal material under an area which had previously undergone erosion during an extended time.

With the earth's crust in isostatic equilibrium, it is difficult to see how any material from subcrustal space could work its way through the entire crust and be exuded at the surface as a lava overflow. The pressure exerted by a column of liquid material extending from the earth's surface to the bottom of the crust would be enormous, and this pressure would be sufficient to fracture rock and make a lava overflow at some point whose altitude is much less than the top of a volcano. According to the Pratt theory of isostasy the overflow of lava from a fissure or from a volcano is probably caused by an expansion of the crustal material below. No extra mass has been added to the prism of the crust involved. It is merely a case of fluid material from some depth within the crust being raised to the surface, increasing the volume of the prism and decreasing the density. Whatever processes cause the uplift of a mountain system undoubtedly cause the volcano and the lava overflow.

It would seem that the earth is gradually losing heat as a result of erosion and sedimentation. As the eroded material is carried away the prism of the crust beneath is forced up to restore the equilibrium.

Erosion may have occurred to the extent of five or ten miles before an uplifted area is base leveled. In such a case every element of the crust beneath would have been raised to a position approximately equal to that distance and would have been brought to a region having a much lower temperature than that of the region from which it came. Eventually there would be a loss of heat at the surface and the material of the prism would be cooled down by 100° to 300°C., depending on how far the crustal material had been pushed up. That heat lost would not be compensated by any heat gained in other places. The areas of heavy erosion later become synclinoria into which sediments are deposited. The sediments accentuate the synclinoria resulting in a pushing down of crustal material into hotter regions. Eventually this material takes on the temperature of its new position, expands to form mountain systems or plateaus and again loses heat at the surface. What maintains the heat of the earth no one knows. There have been many theories, including the one now advocated by many that the disintegration of radioactive materials replaces heat in sufficient amounts to cause the surface of the earth to remain at a practically constant temperature. Be this as it may, we cannot escape the conclusion that the raising up of crustal material under areas of erosion brings hotter material to the surface with a consequent loss of heat.

It is rather difficult to see how a volcano could come into being out in the middle of an ocean but, in general volcanoes are merely a part of a region that is higher than the surrounding bottoms of the ocean. The Hawaiian Islands, for instance, occupy a long stretch extending for some 1200 kilometers while the average width of the pedestal on which the islands rest is of the order of magnitude of 140 kilometers. There must have been light crustal material where the islands now are at the beginning of the sedimentary age and the uplifts and subsidences of the Hawaiian area have been the result of erosion, sedimentation and to a certain extent of the accumulation of rock from coral growth. It is very difficult to explain a chain of islands out in an ocean without assuming under it crustal material which has been lighter than normal density from the beginning of the sedimentary age.

This brief sketch of the relation of isostasy to geological and geophysical problems is only the skimming of the surface of a tremendous problem. It is hoped that much thought and investigation by those interested in the subject will supplement the very meager data which we now possess.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

GEOLOGICAL SOCIETY

407TH MEETING

The 407th meeting was held at the Cosmos Club, October 28, 1925, Vice-president HEWETT presiding.

Program: C. K. WENTWORTH and E. T. APPEL: *A source-analysis of geologic literature on North America, 1921–22.*

N. H. DARTON: *Pre-Paleozoic surface of Arizona and New Mexico.*

R. S. BASSLER: *Mississippian rocks in northern Tennessee.*

408TH MEETING

The 408th meeting was held in the auditorium of the Interior Building, November 11, 1925, President STEPHENSON presiding. The Secretary announced the election to corresponding membership of W. A. NELSON, State Geologist of Virginia.

Program: A. H. REDFIELD: *Petroleum possibilities of Germany.*

H. S. WASHINGTON: *The 1925 eruption of Santorini.*

H. T. STEARNS: *The volcanoes of Japan in 1924.* In Japan and the islands nearby there are 74 active volcanoes which are aligned in narrow curved zones forming arcs that follow closely the crests of a series of great folds in the crust of the earth. It is generally supposed that the magma supplying the volcanoes exists in rifts or fissures that coincide largely with the axes of the folds. The chief volcanic zones are as follows: the Kurile, the Nasu, the Kampu, the Fuji, the Hakusan, the Aso, and the Kirishima zones.

The Kurile zone comprises a line of small volcanic islands which extends from Kamchatka to Volcano Bay on the southern side of the island of Hokkaido. Three eruptions on this zone during 1924 were recorded by a steamer. On February 15, 1924, a huge cauliflower cloud was seen rising from a volcano on Raikokejima, and at the same time two submarine eruptions occurred not far from Matau Island.

The Nasu zone extends from the islands a few miles north of Hokkaido through Volcano Bay to Fujiyama. During 1924 there were gaseous emanations sometimes accompanied by light ash falls from the crater of Asamayama on this zone. Parallel with and west of the Nasu zone is the Kampu zone. No volcanoes on this zone were in eruption during 1924.

The Fuji zone extends south from Fujiyama to the Bonin Islands. A small cinder cone in the center of the crater of Mihara, the central cone of the volcano Oshima located in the Bay of Tokyo, emitted huge volumes of steam during the writer's visit on December 16, 1924. At the same time heavy blue fumes were being discharged with a hissing sound at a high temperature. No glow from molten lava was visible in the daylight. The lava flow on the floor of the crater had not entirely cooled for heat rose from many cracks in its surface.

The Hakusan zone extends from Kyushu along the northern side of Hondo, the mainland of Japan. On January 23, 1925, Shiranesan (Kusatsu) located on this zone, emitted a huge volume of smoke and on the 24th, a heavy explosion occurred with loud rumblings, and ash fell over the surrounding area.

Aso-dake, on the Aso zone, which crosses Kyushu from northeast to southwest, had one explosion on January 9, 1924. On January 6, 1925, it again ejected ashes which caused damage to the farms at its base.

The Kirishima zone extends from Kirishima southwestward toward Formosa. Sakurajima was in repose during the writer's visit in 1924, although it was reported that a fumerole in the summit crater occasionally sent up a column of white steam. Kirishima volcano was not active during 1924, although on December 21, 1924, a hot fumerole inside of a small cone existed on the southeast wall of the summit crater. (*Author's abstract.*)

JOINT MEETING

A joint meeting of the Society and the WASHINGTON ACADEMY OF SCIENCES was held at the Cosmos Club, November 19, 1925, President KELLOGG of the ACADEMY presiding.

Program: Professor WILLIAM H. HOBBS, of the University of Michigan: *The glacial anticyclones—the poles of the atmospheric circulation.*

409TH MEETING

The 409th meeting was held at the Cosmos Club, November 25, 1925, President STEPHENSON presiding. The Secretary announced the death of J. K. HILLERS, a founder and active member of the Society, the resignation of L. B. PUSEY from active membership, and the election to active membership of E. R. POHL, GEORGE TUNELL, T. B. NOLAN, H. W. HOOTS, and P. G. NUTTING.

Program: C. E. RESSER: *Human and geographic aspects of the 1925 Smithsonian-Princeton Expedition to Europe.*

E. O. ULRICH: *European Paleozoic stratigraphy and stratigraphers.*

410TH MEETING

The 410th meeting was held at the Cosmos Club, December 9, 1925, President STEPHENSON presiding. Vice-president HEWETT took the chair during the presentation of the address of the retiring president. This address, entitled *"Major features in the geology of the "Atlantic and Gulf Coastal Plain,"* was printed in this JOURNAL (vol. 16, pp. 460–480).

THIRTY-THIRD ANNUAL MEETING

The thirty-third annual meeting was held at the Cosmos Club after the adjournment of the 410th meeting, President STEPHENSON presiding.

The annual report of the secretaries was read and approved. The Treasurer presented his annual report showing an excess of assets over liabilities of $1,137.49 (book value) on December 9, 1925. The auditing committee reported that the books of the Treasurer were correct. The Amendment to the Standing Rules restoring dues of active members to $2.00 was unanimously carried. The Society accepted, upon recommendation of the Council, the anonymous offer, through KIRK BRYAN, of three prizes of $10 each for excellence of presentation of papers during 1926.

The results of balloting for officers for the ensuing year was as follows: *President:* N. H. DARTON; *Vice-Presidents:* W. T. LEE, CHARLES BUTTS; *Treasurer:* J. B. REESIDE, JR.; *Secretaries:* J. D. SEARS, W. P. WOODRING; *Members-at-Large-of-the-Council:* B. S. BUTLER, S. R. CAPPS, G. R. MANSFIELD, O. E. MEINZER, C. N. FENNER; *Nominee as Vice-President of Washington Academy of Sciences representing the Geological Society:* L. W. STEPHENSON.

411TH MEETING

The 411th meeting was held in the auditorium of the Interior Building, January 13, 1926, President DARTON presiding.

Program: W. W. RUBEY: *Stream piracy in northeastern Wyoming.* Extreme northeastern Wyoming is drained by the Little Powder, Little Missouri, and Belle Fourche rivers. Little Missouri River, the central of the three, has the lowest gradient and field evidence indicates it has been and will be robbed by both the neighboring streams. The ancient capture of the headwaters of the Little Missouri by the Belle Fourche River at Stoneville Flats is well known. Old terraces and topographic relations seem to show that a tributary of Little Missouri River formerly flowed northwestward along the present course of Belle Fourche River between Stoneville Flats and Belle Fourche, S. Dak. This capture is attributed chiefly to foreshortening of the Cheyenne River as a result of the advance of Pleistocene glaciation, although the diversion of the lower Little Missouri River by an ice sheet had a slight additional effect. Field evidence indicates that the resulting rejuvenation worked slowly upstream and that the capture may have occurred at about the end of the Pleistocene. Tributaries of Belle Fourche River will eventually divert the remaining headwaters of Little Missouri River.

The lithology of old gravels, the present stream gradient, and the land forms near the head of Belle Fourche River, and the sharp bend and terraces of Powder River suggest that the present Belle Fourche River formerly rose in the Big Horn Mountains, but was beheaded near Pumpkin Buttes by Powder River. This capture, which possibly occurred at the beginning of the Pleistocene, may be the result of greater precipitation in the Powder-Yellowstone drainage system than in the ancient Little Missouri system.

Little Powder River is preparing to behead the Little Missouri and perhaps the Belle Fourche River. The latter case of incipient piracy may be a readjustment following the capture at Stoneville Flats. (*Author's abstract.*)

KIRK BRYAN: *The "Palouse soil" problem of the Columbia Plateau, Washington.* One of the conspicuous features of the Columbia Plateau is the mantle of soil which blankets the surface of the underlying rocks. The fine-grained unconsolidated material is in places 100 to 150 feet thick, and it is intimately dissected into hills by miniature ramifying valleys. Since this material is everywhere of about the same thickness and conforms to the general slope of the plateau, it is a natural assumption that it once formed a continuous cover and has since been dissected. With the assistance of a number of colleagues, somewhat scattered information about this so-called soil has been brought together and an analysis of the origin and age of the material made. In general the upper 3 to 6 feet of the material is a top skin or veneer that throughout the plateau is largely wind-borne. It rests on various sorts of material and the underlying mass that forms the inner core of the hills is generally unexposed and unknown. At various places there has been identified (1) laminated silt; (2) reddish compact silt with limy concretions, apparently an old loess; (3) yellow clay that microscopic examination shows to be an old loess; (4) ancient glacial till. In places in the eastern part of the plateau the yellow clay, or old loess rests on thin decomposed basalt but in the western part of the plateau the more sandy mass rests on nearly fresh basalt. Here below the general level there is a terrace covered by similar wind-borne soil in which the bones of an elephant were found. On this account, and in view of the association of the material with glacial till it is evident that the "Palouse soil" is of Pleistocene age.

A review of the known facts in regard to present dust storms indicates that these remarkable meteorological phenomena have been in operation only for the past few decades since the grass cover of the plateau was broken by ploughing. If the present rate of fall of dust as estimated for Spokane had been in operation since Wisconsin time there would be 16 inches of dust on the Wisconsin terrace whereas this terrace is free of dust. Similarly the pre-Wisconsin till plains and terraces (Spokane glaciation of Bretz) are almost free of dust. A still older till has a cover of 16 inches to 3 feet of loess and in other places the cover on the ancient till may be greater. Therefore, the time of formation of main loess ("Palouse soil") seems to be far back in Pleistocene time. (*Author's abstract.*)

LAURENCE LAFORGE: *The recognition of peneplains.*

412TH MEETING

The 412th meeting was held at the Cosmos Club, January 27, 1926, President DARTON presiding. The Secretary announced the resignation from active membership of MISS LUCY M. JONES.

Program: W. T. SCHALLER: *The mineralogy of the Tintic Standard mine, Utah.* The oxidation of silver-rich galena, silver-rich tetrahedrite, pyrite, and other sulphides, has yielded a number of unusual and rare minerals chiefly sulphates. Among these may be mentioned kornelite, ferropallidite, plumbojarosite, and argentojarosite. The plumbojarosite has formed, in part, directly from cerussite, but no evidence was seen that the argentojarosite had formed in any way but by the commingling of sulphate solutions of silver and iron. Some galena, partly oxidized to anglesite, forms a eutectic-like structure with it. Chains of orthorhombic sulphur crystals (similar to artificial ones) suggest paramorphism from earlier higher temperature monoclinic crystals. Rectangular casts suggest the one time presence of anhydrite. Most of the minerals mentioned probably formed from rather hot solutions. (*Author's abstract.*)

H. G. FERGUSON: *Regional relations of Nevada ore deposits:* The two-fold division of Nevada ore deposits into those formed at depth associated with granitic intrusive and those formed near the surface in connection with Tertiary volcanics has long been recognized. Evidence is accumulating suggesting that each of these groups should be again divided. The great Sierra batholith intruded at about the close of the Jurassic carries on its western flank satellitic batholiths with which are associated the quartz veins which have yielded the great California gold production. On the eastern flank the geologic conditions are similar but the veins accompanying the satellitic batholiths, though similar in appearance and mineralogy to those of California, have yielded no important gold production. Owing to favorable climatic conditions, however, these western Nevada veins have undergone secondary enrichment in silver, and it was from these rich secondary ores that the great silver production of such camps as Austin and Belmont was obtained. These were for the most part exhausted many years ago. Replacement and contact deposits are relatively rare. The Sierra region yields a very small percentage of the country's production of base metals, chiefly copper. A very different condition prevails in the interior region. Here intrusions of Eocene age have associated with them deposits, chiefly of the replacement type, valuable chiefly for base metals, and the vein type of deposit though present is not predominant.

The line of division between the two prevailing types seems to pass through the middle of Nevada. To the west the deposits are mostly of the vein type, rich in silver near the outcrop but disappointing in depth. In the eastern part of the State on the other hand the rich secondary silver ore at the outcrop in many places passed in depth to workable lead-silver ore. The inference is drawn that the Western Nevada veins deposits allied with the Sierra batholith were formed at about the close of the Jurassic, whereas those in the eastern part of the State, showing strong affinities with the Rocky Mountain type, should be tentatively placed in the Eocene. This is not in accord with Lindgren's suggestion that the locus of the Cordilleran intrusions moved gradually eastward but implies two distinct and widely separated periods of batholithic intrusion.

The proposed division of the near-surface deposits is based largely on work in the region of the Tonopah and Hawthorne degree sheets. Here certain deposits such as those of Tonopah and Aurora are associated with lavas of pre-Esmeralda age, that is, older than the upper Miocene. Manhattan, Round Mountain, Goldfield, Bodie, and a number of less important deposits are definitely post-Esmeralda in age. The deposits of the Tonopah-Aurora type are so widespread over Nevada that it is surmised that this was the major period of late Tertiary mineralization. The characteristic features are strong veins, the presence of primary argentite and commonly other silver minerals, free gold heavily alloyed with silver, usually about equal parts by weight, and often fairly abundant base metal sulphides. Although many of these are properly gold camps if value of output is considered, in all cases the weight of silver produced greatly exceeds that of the gold. This type is widespread; it is well represented in Mexico, New Zealand, and the East Indies and has been called the Pacific type of ore deposit. Of the relatively few deposits with predominant gold, Bodie, Goldfield, Manhattan, and Round Mountain are known to be of post-Esmeralda age, and it is inferred that further work may place the others there also. These deposits do not form as distinct a class as the pre-Esmeralda group. In most of the less important and also Round Mountain, Bullfrog, Oatman, and part of the Manhattan district, free gold is the only important metallic mineral, the amount of sulphides being very small and barren. In Goldfield, and part of the Manhattan district, however, complex mineral associations prevail. Commonly, the veins are less persistent and less well defined than those of the earlier type. Primary bonanzas of great richness may occur, but the productive depth is on the average less than in the pre-Esmeralda silver deposits.

Although it will be many years before the succession of lavas throughout the Great Basin is well enough known to speak with any certainty, the available evidence points to a widespread mineralization prior to the Upper Miocene. This is allied in type and therefore possibly in age with deposits in all regions bordering the Pacific. The post-Miocene deposits are of different character and possibly only of local importance. It appears, therefore, that there have been four distinct periods of major mineralization in Nevada. The first is closely allied to the Sierra gold type, but unfortunately deficient in gold, of post-Jurassic age, and prevails in the western part. The second which might be called the Rocky Mountain type, prevails in the eastern part of the state, and is probably of Eocene age. Mineralization of probable Miocene age with predominant silver was widespread, while a later period probably early Pliocene, has yielded relatively few deposits of importance. (*Author's abstract.*)

W. G. ALDEN: *The Gros Ventre landslide of June, 1925.* On June 23, 1925, there occurred in the valley of Gros Ventre River, about 35 miles south of Yellowstone Park and near the east side of Jackson Hole, Wyo., a landslide which carried down from the adjacent slope and deposited in the valley many million cubic yards of rock debris. This slide, which occurred within a space of a few minutes, formed a dam about 225 feet high and half a mile long, which completely blocked the river and so impounded the water as to form a lake 4 or 5 miles long, with a maximum width of about three-quarters of a mile. This lake submerged much of three private ranches and one ranger station of the Teton National Forest, and has created a situation more or less perilous to ranches and villages all the way down the Gros Ventre and Snake River valleys. This appears to have had no connection with the Montana earthquake which occurred four days later. The Gros Ventre valley in this part is cut several thousand feet into upturned Cretaceous, Jurassic, and Triassic rocks. The slide occurred at the heavily wooded north end of the long north spur of Sheep Mountain, one of the northern peaks of the Gros Ventre Range. It was probably due to the saturation of clay shale interbedded with the Carboniferous limestones and sandstones as the result of heavy rains and melting snows. The strata at this place, on the south side, dip into the valley at angles of 18 to 21 degrees, and the movement was obliquely down the dip. The upper end of the slide is at the top of the slope about 1½ miles south of the river and 1700 to 2200 feet above it. The front of the great mass of rock debris and forest trees plunged across the half-mile-wide valley bottom and piled up 400 feet high against the red sandstone cliff on the north, then settled back somewhat. The flooded stream rapidly filled the basin thus formed and in about three weeks the water rose 220 feet back of the dam. It is estimated that about 150,000 acre feet of water was impounded over 2000 acres of land. As the inflow decreased, seepage began and increased to 400 or 500 second feet, so that the dam was not overtopped. It was reported late in January, 1926, that no particular change in conditions had taken place up to that time. The great point of interest is as to what will occur next spring, inasmuch as it seems certain that the dam must be overtopped if there is any such spring flood as occurred in 1918 when the flow at Kelly, four miles below the site of the dam, reached a peak of 6000 second feet and averaged 4000 second feet for two weeks. (*Author's abstract.*)

413TH MEETING

The 413th meeting was held at the Cosmos Club, February 10, 1926, Vice-president LEE presiding.

Program: R. T. EVANS: *Erosion forms in Zion National Park, Utah.* W. T. LEE: *Some scientific aspects of the Mammoth Cave region, Kentucky.*

414TH MEETING

The 414th meeting was held at the Cosmos Club, February 24, 1926, President DARTON presiding. The Secretary announced the election to active membership of PARKINSON POPINOE and Miss TAISIA STADNICHENKO. W. T. SCHALLER was awarded by ballot the prize of $10 for excellency in presentation of papers during the first third of 1926.

Program: H. W. HOOTS: *Geologic features of the southern end of the San Joaquin Valley, California.* The San Emigdio Mountains lie at the southern end of the San Joaquin Valley. They trend in an east-west direction and,

together with the Tehachapi Mountains farther east, form that elevated area which connects the southern end of the Sierra Nevada range with the Coast Ranges. The geologic character of the San Emigdio Mountains, broadly considered, is intermediate between that of the Sierra Nevada range and that of the eastern Coast Ranges of this region in that it has a central mass of granodiorite which connects with the Sierra Nevada, and a northern foothill belt of highly disturbed Tertiary sediments which broadens progressively westward. The San Andreas fault lies south of the San Emigdio Mountains, trends S 80° E, and separates the granodiorite from a much folded and faulted mass of Tertiary strata. Approximately 24,000 feet of Tertiary and Quaternary sediments, ranging in age from Eocene to late Pleistocene, lies north of the granodiorite. These rocks, consisting of massive sandstone and conglomerate, soft shale, volcanics, and coarse fanglomerate are folded into pronounced anticlines and synclines with east-west trend and are broken by many faults. All major folds, without exception, have their north-dipping limbs the steeper with inclinations of 45°–60° in contrast to south-dipping limbs of 20°–30°. The major faults, one of which appears to be an overthrust of low angle south dip, also trend east-west, approximately parallel to the San Andreas fault farther south, and have stratigraphic displacements as great as 5,000 feet; minor faults, apparently with vertical planes, trend either northeastward or northwestward. It is considered likely that these structural features have resulted from northward thrusts from the south during late Tertiary and Quaternary time similar in effect to those which, during the earthquake of 1906, produced relatively northward movement of the fault-block west of the San Andreas rift. That movement of this western fault-block has actually been northward during the past 30–40 years is attested by recent resurveys of the Coast Ranges by the U. S. Coast and Geodetic Survey. Wheeler Ridge, the topographic expression of one of the most prominent east-west trending asymmetrical anticlines, lies at the northern edge of the foothills directly in front of the major fault which appears to be of low-angle overthrust type. Study of its structural details and probable origin leads one to believe that it has been subjected to thrusts from the south since the anticline, developed in late Pliocene and Pleistocene strata, was formed. In conclusion, the stratigraphy, pronounced development of solifluction and large earth-flows, and the physiographic history of a part of the foothill region were briefly described. (*Author's abstract.*)

F. L. Hess: *The source and use of cesium.* Pollucite is the only known cesium-bearing mineral and it has been found only on the Island of Elba, where it was discovered and occurs as a mineralogical curiosity. At Buckfield, Maine, it has been found in comparatively large quantity and a few thousand pounds has been mined. The pegmatite which has been mined during the last summer by W. D. Nevel and previously by Perien S. Dudley, is an almost diagrammatic representation of the theory brought out by the writer[1] of the gradual growth of pegmatites from fine grained masses to those containing huge individual crystals or masses of single minerals. A dike of coarse granite about 15 feet wide cuts across the gneiss on Hodgeon Hill, 3½ miles southwest of Buckfield. Following a crack in the granite and lying close to one side is a mass of pegmatite, following a rather irregular course and varying in width from 3 or 4 feet to perhaps 10 feet. In places the

[1] Hess, Frank L. *The natural history of pegmatites.* Engin. and Min. Journ. 120: 289–298. 1925.

pegmatite is composed of irregular masses of microcline, biotite, muscovite and quartz. Within these masses are bodies of rock which are composed of crystallized microcline, individual crystals of which may be 5 or 6 inches through. With the crystallized microcline, is, in places, clevelandite (platy albite) cassiterite, blue and green tourmalines, colorless pink and blue beryl of indistinct crystal form, and pollucite. The pollucite is usually without form, partly glassy and partly crushed to a powder. The pollucite is found only where the microcline is crystallized and with the higher temperature minerals just noted. It is usually surrounded by a coat of lepidolite about 1/32 inch thick, normal to the pollucite, and veinlets of pale lepidolite cut the pollucite. At places in the pegmatite radial veinlets not much thicker than a hair are filled with arsenopyrite and at the ends of the rays are crystals of black tourmaline. Cracks running into the dike show incipient pegmatitization. (*Author's abstract.*)

C. P. Ross: *Some features of the Paleozoic stratigraphy of Idaho.* A large part of Idaho has now been geologically studied in reconnaissance fashion and detailed work has been done in a number of localities. Although much of the latter is still unpublished it was available in the preparation of the present paper. Only in the southwestern part of the State is it likely that facts of major stratigraphic importance await discovery, although a multitude of details are still unknown in almost all parts of the State. In spite of the bewildering rapidity of change in the Paleozoic stratigraphy within short distances in many parts of the State, it has been possible to construct more or less tentative stratigraphic columns for nearly all parts of Idaho and to work out some of the broader features of the Paleozoic stratigraphy. During much of the Paleozoic a narrow sea extended north from its connection with the Pacific near Lat. 35 N, along the present position of the Rocky Mountain Cordillera, covered much of eastern Idaho, and had frequent connection with the Arctic Ocean. The Cambrian sea in Idaho extended north as far as the 45th parallel and west beyond the 115th meridian. A sea also covered part of northern Idaho in the Cambrian but probably had no connection within the State with that in the south. The other Paleozoic seas did not extend as far north or west as did the Cambrian, but deposited many thousands of feet of sediments in southeastern and southcentral Idaho. The only known Paleozoic beds in western Idaho are of Carboniferous age. In the Permian, at least, the sea here had a connection with that in eastern Idaho. This connection may have been across the central part of the State, where volcanic strata of supposed Permian age have recently been found, but more probably was across southern Idaho or northern Nevada. The position of the shoreline probably shifted almost constantly during the Paleozoic but in general corresponded fairly closely with the eastern boundary of the so-called Idaho batholith, a fact which is probably of structural significance. (*Author's abstract.*)

Program: M. R. Campbell: *The meaning of cut-off meanders in tidal streams.* The presence of stream meanders and of cut-off meanders on the tidal streams of Virginia raises the question of the conditions under which such features will be developed and consequently their value in interpreting the geomorphic history of the region in which they occur. A study of the lower Mississippi, the San Jacinto River below Houston, Texas, and the James River from City Point to its mouth shows that as soon as a stream reaches tide water it loses most, if not all of the features and habits of a normal stream and in this condition there is little or no tendency to form meanders

or to cut them off. If this conclusion is correct, the presence of meanders or meander scars at any particular level indicates that at the time that level or terrace was formed the stream was above tide level and behaved as a normal stream behaves. The application of this principle should materially assist in deciphering the recent geomorphic history of the embayed section of the Atlantic Coastal Plain. (*Author's abstract.*)

WILLIAM BOWIE: *The importance of geophysical data in geologic research.*

415TH MEETING

The 415th meeting was held at the Cosmos Club, March 10, 1926, President DARTON presiding. The Secretary announced the transfer of the following members from the active list to the corresponding list: ARTHUR HOLLICK, ROBERT ANDERSON, H. F. BAIN, J. P. BUWALDA, ERNEST HOWE, T. C. HOPKINS, W. S. BURBANK.

F. E. MATTHES: *Some examples of the cellular structure of ice.* The speakers showed several lantern slides of photographs taken by him in Rock Creek Park, Washington, D. C., on Jan. 24, 1926, of cakes of ice in which the cell structure, as it is termed by some authors, had been rendered clearly discernible at the surface by a fortuitous train of circumstances. After the ice on the ponded stretches of Rock Creek had attained a thickness of about 5 inches, a change in weather brought about a flood, which broke up the ice and cast large cakes of it on the banks of the stream. There, exposed to the mild heat of the winter sun, the surfaces of the cakes became etched along the lines of contact between the cells, the interstitial films, or cell walls being more sensitive to radiant heat than the crystalline ice, as has recently been shown experimentally by E. K. Plyler. A brief snow flurry then supervened and the etched grooves were filled with fine powdery snow, the result being that each individual ice cell stood clearly outlined by a white boundary. The photographs revealed great variety in the horizontal dimensions of the cells. As a rule the cells measured only a quarter to half an inch across, but some of them measured an inch or more across. A few cakes contained cells measuring 3 to 7 inches to the side. The commonly accepted theory is that each cell envelops a single crystal, and this is probably true of the small and medium-sized cells, which largely preponderate; but it scarcely seems probable that the very large cells mentioned contain each but a single crystal. As a matter of fact, when the ice composed of these large cells was broken, there were revealed vertical flutings along the cell walls as well as a dim structure here and there within the cells themselves, suggesting the presence of a multitude of thin, almost fibrous, crystals closely intergrown. It may well be, therefore, that ice cells and ice crystals are not always coterminous, but that under certain conditions aggregates of crystals may be enveloped by one cell. The observation made, though lacking verification by microscopic analysis, may have a bearing on the probable composition of the interstitial films. There are in the main two views: (1) that these films consist of water holding salt or other mineral matter in solution and therefore having a low freezing point; (2) that they are made up of loose molecules of ice not definitely attached to the lattice work of the crystals. It seems entirely possible that both kinds of interstitial films are present in ice; the latter normally separating crystal from crystal, the former being present wherever there are appreciable quantities of dissolved mineral matter in the water, and being segregated as freezing goes on, in the form of so-called cell walls that may enclose one or more crystals of pure ice. (*Author's abstract.*)

416TH MEETING

The 416th meeting was held at the Cosmos Club, March 24, 1926, President DARTON presiding. The Secretary announced the resignation of C. D. DAVIS, a founder and active member, and the transfer of the following members from the active list to the corresponding list: M. W. BALL, W. C. PHALEN, C. M. KEELER.

Program: FRANK REEVES: *The landslide origin of the thrust faults around the Bearpaw Mountains.* The thrust faulting in the plains on the north and south sides of the Bearpaw Mountains is apparently confined to the weak upper Cretaceous and early Tertiary formations. The trend and extent of the faults indicate that they were produced by a thrust force acting outward from the mountains. The slight plainsward inclination of the strata toward the faulted area suggests the possibility that during the mid-Tertiary period of volcanic activity in the mountains, these formations, being buried under an enormous load of extrusive material and subjected to violent and frequent earthquake shocks, slipped plainsward on wet bentonite beds in the upper part of the Colorado shale, resulting in the compression and thrust faulting of these formations in the plains. *(Author's abstract.)*

B. S. BUTLER: *Some features of the native copper deposits of Michigan.*

N. H. HECK: *Some unusual submarine features in the north Pacific Ocean.* The area referred to in the paper includes the rim of the North Pacific ocean from the Panama Canal to the Philippine Islands. A deep ocean trough developed by the Coast and Geodetic Survey Steamer GUIDE in 1923 is found to be associated with a large number of earthquake epicenters along its extent from Panama to the Gulf of Lower California. Another series of epicenters further off shore are in line with a series of oceanic islands and reefs. From Lower California to Alaska submarine activity appears limited. There are a number of cases of submarine earthquakes along the extension of the San Andreas fault off the coast of Northern California. Attention was called to the existence of a submarine crater off the coast of southeastern Alaska, and there was brief discussion of the pinnacle rocks found in the waters of southeastern Alaska. Special attention was called to the small base and consequent very steep slopes of the sides of these pinnacles. The Yakutat Bay earthquake of 1899 was accompanied by a vertical change reaching nearly 50 feet, the greatest heretofore recorded in a single earthquake on land during the historic period. Besboro Island in Bristol Bay north of the Aleutian Islands rises to a height of 1600 feet in a generally flat region. It is probably the remains of volcanic cone. Volcanic activity in this region resulted in the formation in a comparative recent period of Bogoslof Island north of the Aleutian chain. Paralleling the Aleutian chain to the south there is a great deep extending from the mainland of the Aleutian Islands to Kamchatka apparently without break, though the soundings are few. It was pointed out that the extension of the axis of this deep follows a submarine valley to the Alaska coast, reaching it at Yakutat Bay. Many earthquake epicenters are associated with this deep and there is evidence of considerable activity to the south of it. A series of deeps from Kamchatka along the Japanese Islands to the Philippines are well known to be the most active seismic region of the earth. A number of epicenters plotted within the outlines of the deep bring this out very clearly. It is here that the greatest known ocean depths are found. Another branch extends from Japan through the Marianna Islands, a very active region with earthquakes of both volcanic and tectonic character.

The need for complete surveys of the North Pacific in order to understand these features better was stressed. A case of sudden change in depth over a limited area greater than that recorded at the time of the Yakutat earthquake was described. In the Cuyo Islands in Zulu Sea, Philippine Islands, an area of about half a square mile dropped an average amount of 100 feet between two surveys eighteen months apart. An earthquake occurred during the period. This case has been published in detail in the Geographical Review for April, 1926, by Lieut. Com. F. H. Hardy of the Coast and Geodetic Survey. (*Author's abstract.*)

417TH MEETING

The 417th meeting was held at the Cosmos Club, April 14, 1926, President DARTON presiding. The Secretary announced the transfer of the following members from the active list to the corresponding list: J. M. HILL, C. K. WENTWORTH, O. B. HOPKINS, R. W. STONE, F. L. RANSOME, T. W. VAUGHAN, H. F. SACKETT.

Program: W. P. WOODRING: *Geologic history and paleobiologic significance of the genus Clementia. Clementia* is a clam-like bivalve mollusk that has a characteristic *Inoceramus*-like sculpture. A review of all the known fossils indicates that this genus first appeared in the eastern tropical Pacific or in the Caribbean region during middle Eocene time. It may represent an invading type in both these regions, for a divergent phylum appeared at virtually the same time in the Paris Basin. It is assumed that the genus migrated into the Orient by way of the north border of the Pacific during early or middle Tertiary time and that the isolated Miocene finds in the Mediterranean region represent a temporary invasion from the Orient. After Miocene time the main phylum completely disappeared in American and European waters and all the living species are found in the western Pacific and Indian Oceans. During Miocene time another divergent phylum, known as the subgenus *Egesta*, arose in American waters. It also migrated around the north border of the Pacific. After Miocene time this subgenus also disappeared in American Atlantic waters, but one species still lives in the Gulf of California. The only other living species is found in the waters off Japan and Chosen. *Clementia* is a mud-burrower and its shell, like that of other mud-burrowers, is very thin. Living species are found either in very shallow protected water or in deeper exposed water at a maximum depth of 85 fathoms. The fossils are found in mud beds almost invariably with both valves in attached position, showing that they died and were buried at the place where they lived. Fossil species of *Egesta* are found in both mud and sand beds and their shell generally is thicker than that of *Clementia*. *Egesta* tolerated a lower range of temperature than *Clementia*. All the fossil species from the United States and Mexico represent *Egesta*, whereas all the species from the Caribbean region and the Pacific coast of Central America and northern South America represent *Clementia*. (*Author's abstract.*)

CHARLES BUTTS: *The Devonian of Alabama and the unconformity at its base.* Omitting the Chattanooga shale, the age of which is in dispute, the Devonian system is not well represented in Alabama. There is a very small area of limestone of Helderberg, probably New Scotland, age in the northwestern corner of the State which extends into the State from the Tennessee Valley area in Tennessee on the north. The Jemison chert with *Meristella lata* of Oriskany age, and the Yellow Leaf quartz schist overlying the Jemison chert, crop out in a narrow belt in Chilton County in the vicinity of Jemison.

The Jemison is known only by its chert which resembles the chert of the older Copper Ridge dolomite and was mapped on the 1894 edition of the geologic map of Alabama as Knox dolomite. Both the Jemison chert and the Yellowleaf quartz schist are members of the Talladega slate as it has been delimited in Alabama. In a broad belt extending northwest to Georgia from the Coastal Plain between Tuscaloosa and Talladega counties, are beds of sandstone and shale of Devonian age. In Red Mountain southwest of Bessemer characteristic Oriskany fossils were obtained from a quartzite and chert 8 inches thick underlain by 5 feet of sandstone, which may also be Oriskany. Oriskany fossils were also obtained from chert 1 mile southwest of Vance, Tuscaloosa County. Northeastward in Cahaba and Coosa Valleys the Devonian is represented mainly by shale and sandstone from 2 to 50 feet thick overlying limestone of Beekmantown or Little Oak (Chazy) age or, in Shelby and Bibb counties, the Athens shale, also of Chazy age, which underlies the Little Oak limestone. The Devonian in this belt is entirely of Onondaga and Hamilton ages. It includes the sandstone of Frog Mountain in Cherokee County, which was named by Hayes the Frog Mountain sandstone and which was considered as of Oriskany age. The name Frog Mountain has been also applied to the beds of Devonian age throughout all of this belt, that is, all the Devonian in Alabama except the Helderberg in the northwest, the Jemison chert, and the Yellowleaf quartz schist has been designated Frog Mountain sandstone. Among the most notable exposures and fossil localities of the Devonian in this belt are those at Watkins Cut 1 mile east of Odenville and in an abandoned quarry 1½ miles south-southwest of Ragland, 25 miles northeast of Birmingham. At the Ragland locality the Devonian is fully exposed in the quarry face and is composed of a thin limestone below and of shale and sandstone with cherty nodules above, the whole being 54 feet thick. Here the lower 4 feet is profusely fossiliferous, the coral fauna being most conspicuous, and recalling the rich coral fauna of the "Falls of the Ohio" at Louisville, Ky. The entire fauna contains both Onondaga and Hamilton forms, the latter predominating. The lower limestone of the Devonian, eight inches thick, is here cemented to the underlying Little Oak limestone along a very even contact, notwithstanding a hiatus due to the absence of several thousand feet of rocks, including all the Black River, Trenton, Utica and Loraine of the Ordovician, the Richmond, the entire Silurian, and the Lower Devonian. A full description of the Devonian is contained in the Geology of Alabama, pp. 141–158, 1926, published by the Geological Survey of Alabama. (*Author's abstract.*)

J. B. MERTIE, JR.: *Stratigraphy of the Upper Yukon Valley.*

418TH MEETING

The 418th meeting was held at the Cosmos Club, April 28, 1926, President DARTON presiding. The Secretary announced the transfer of D. F. MACDONALD from the active list to the corresponding list:

Program: KIRK BRYAN: *Solution-facetted limestone pebbles.*

G. R. MANSFIELD: *Summary of the geology of southeastern Idaho with notes on recent work.* The strata of southeastern Idaho include about 46,000 feet of sedimentary rocks, which are grouped in 41 formations, embracing lower middle Cambrian to Quaternary rocks and representing every period within that interval. There are many varieties of igneous rocks, but only three principal types—hornblende andesite porphyry, rhyolite, and olivine basalt. Five to eight epochs of volcanic activity have been recognized. The

structural features include many folds, some as long as 75 miles, the Bannock overthrust, the Blackfoot fault, which is a transverse thrust, and the Meadow Creek graben, besides other faults both normal and reverse. Thirteen physiographic stages have been identified and described. These features have been discussed in earlier brief papers and in a professional paper now in press. The more recent field studies have been in the Portneuf, Paradise Valley, and Ammon quadrangles, where additional folds and faults have been mapped. A window in the Bannock overthrust appears in the Portneuf quadrangle, and the Bannock overthrust itself is exposed in several branches in the two other quadrangles named. It passes beneath cover of Tertiary beds and lavas in the southern part of the Ammon quadrangle. (*Author's abstract.*)

B. C. RENICK: *Stratigraphy of the eastern part of the San Juan Basin, New Mexico.*

419TH MEETING

The 419th meeting was held at the Cosmos Club, May 12, 1926, President DARTON presiding. The Secretary announced the transfer of the following members from the active to the corresponding list: EUGENE STEBINGER, LLOYD GIBSON, THEODORE CHAPIN. W. P. WOODRING was awarded by ballot the prize of $10 for excellency in presentation of papers during the second third of 1926.

Program: W. T. SCHALLER: *What is a gem stone?*

C. E. RESSER: *The Cambrian in the Rocky Mountains.* Until a few years ago all work on the Cambrian belonged to the first or "accumulative" stage and but few attempts had been made to weld the gathered facts into a harmonious whole in accord with modern stratigraphic methods. More recently attempts have been made to assemble our information into some sort of order so that the data in hand may be more useful and future field work directed more intelligently. At present the Cambrian beds of Wisconsin, studied by Dr. E. O. Ulrich during the past 12 years, constitute the "standard" with which all other Upper Cambrian strata are being correlated. No "standard" sections exist for the Middle and Lower Cambrian and consequently efforts must be made to find suitable ones. It is estimated that not more than 30 per cent of the Cambrian fossils now in hand have been described. (*Author's abstract.*)

A. J. COLLIER: *The unconformity between the Madison limestone and Ellis formation in northern Montana:* An important unconformity occurs between the Madison (Mississippian) limestone and the Ellis (Jurassic) formation in northern Montana. Knowledge of this unconformity has been obtained from the many wells that have penetrated these formations on the Sweetgrass Arch north of Great Falls and from its exposure near Stocket twenty miles south of Great Falls, in the Sweetgrass Hills near the international boundary and in the Little Rocky and Bearpaw Mountains. The outcrop near Stocket shows a discordance in the dip of the two formations, the surface between them being irregular and occupied by a few feet of gravel sand and soil cemented by secondary silica and iron rust. This deposit comprises the basal "sand" of the Ellis or the "Ellis sand" of the drillers in the Kevin-Sunburst oil field. A few miles south of Stocket a small thickness of the Quadrant formation, (Mississippian or early Pennsylvanian in age) underlies the unconformity and near the Wyoming line Triassic rocks underly it. In the Sweetgrass hills and in the Bearpaw and Little Rocky Mountains the character of the unconformity is about the same as at Stocket though no discordance

in the dip of the associated formations has been observed. In the front range of the Rockies west of the Sweetgrass Arch the unconformity is not exposed owing to the great overthrust fault which extends north and south in Glacier National Park. Near Banff west of this overthrust, however, there is a great thickness of limestone the upper members of which are thought to be younger than Madison and wells drilled about a hundred miles southeast of Banff in the Turner valley of Okotoks oil field have evidently penetrated this limestone below the Jurassic. In the Athabaska region 500 miles north of the Sweetgrass Arch the youngest Paleozoic rocks are Devonian and immediately above them occur the Athabaska tar sands believed to be of lower Cretaceous age. The unconformity here is probably a northern extension of the unconformity underlying Sweetgrass Arch and if so erosion progressed far enough to remove the whole of the Madison formation. This unconformity therefore represents a great peneplain eroded in late Triassic or early Jurassic time which extended about 800 miles north and south and 200 or more miles east and west. It was eroded on Triassic rocks at its south end; on Quadrant and Madison rocks in its middle part and on Madison and Devonian rocks at its north end.

The Ellis-Madison unconformity is of considerable economic importance in northern Montana for the deposits associated with it contain valuable pools of oil in the Kevin-Sunburst field. It may be of equal importance in Canada for the Athabaska tar sands and the oil in Turner Valley apparently are associated with it. (*Author's abstract.*)

420TH MEETING

The 420th meeting was held at the Cosmos Club, November 10, 1926, Vice-president BUTTS presiding. The Secretary announced with regret the death of Dr. W. T. LEE, an active member and First Vice-president for 1926.

Program: E. O. ULRICH and R. S. BASSLER: *Some experiences of European geology and the International Geological Congress.*

421ST MEETING

The 421st meeting was held at the Cosmos Club, November 24, 1926, Vice-president BUTTS presiding. The Secretary announced with regret the death of Dr. F. H. KNOWLTON, a founder and former President of the Society. The resignation of T. K. HARNSBERGER from active membership also was announced.

Program: W. T. SCHALLER: *Origin of polyhalite.*

LAURENCE LAFORGE: *New evidence on the Pleistocene swamps of Washington.*

422D MEETING

The 422d meeting was held at the Cosmos Club, December 8, 1926, Vice-president BUTTS presiding. The Secretary announced the election to active membership of R. C. MOORE, E. T. MCKNIGHT, and C. E. ERDMAN. Announcement was also made of the election to corresponding membership of Dr. H. S. LADD, of the University of Virginia, and of the resignation of R. W. PACK from active membership as of January 1, 1926. On recommendation of the Council it was announced that during the ensuing year the Proceedings of the Society would be offered at least once a month to the editors of the JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES for

publication. Members were urged to present to the Secretary abstracts of papers at the time when they are given. Otherwise the papers will be published by title only, for the Secretaries will no longer consider it their duty to beg for abstracts.

Program: Professor CHARLES P. BERKEY, of Columbia University, addressed the Society on *An outline of the geology of Mongolia.*

THIRTY-FOURTH ANNUAL MEETING

The thirty-fourth annual meeting was held at the Cosmos Club after the adjournment of the 422d meeting, President BUTTS presiding. The annual report of the secretaries was read and approved. The Treasurer presented his annual report showing an excess of assets over liabilities of $1,276.89 on December 8, 1926. The auditing committee reported that the books of the Treasurer were correct.

The results of balloting for officers for the ensuing year were as follows: *President:* CHARLES BUTTS. *Vice-presidents:* S. R. CAPPS, D. F. HEWETT; *Treasurer:* J. B. REESIDE, JR.; *Secretaries:* W. P. WOODRING, W. W. RUBEY; *Members-at-large-of-the-Council:* O. E. MEINZER, H. E. MERWIN, C. S. ROSS, JAMES GILLULY, W. H. BRADLEY; *Nominee as Vice-president of Washington Academy of Sciences representing the Geological Society:* N. H. DARTON.

J. D. SEARS, W. P. WOODRING, *Secretaries.*

SCIENTIFIC NOTES AND NEWS

The Pick and Hammer Club met at the Geological Survey on January 8. The program consisted of reports on the Pan-Pacific Scientific Congress in Japan by W. C. MENDENHALL; on the meetings of Section E of the American Association for the Advancement of Science, at Philadelphia, by G. R. MANSFIELD; and on the annual meeting of the Geological Society of America at Madison, by R. S. BASSLER, M. R. CAMPBELL, W. T. SCHALLER, and ARTHUR KEITH. The Club met at the Geological Survey February 5 to hear a series of short contributions on *The stratigraphy and conditions of sedimentation of the Permian rocks of the Colorado Plateau.* R. C. MOORE, H. D. MISER, C. R. LONGWELL, J. B. REESIDE, Jr., JAMES GILLULY, C. W. GILMORE, and DAVID WHITE contributed to the program.

Professor JOHANNES WALTHER of the University of Halle, Speyer Visiting Professor at Johns Hopkins University for the current year, on March 19 will talk to the Pick and Hammer Club on some of his observations on laterite and red sediments in the deserts of Western Australia. The talk will be illustrated with lantern slides.

The Petrologists' Club met at the Geophysical Laboratory on January 18. W. T. SCHALLER, C. S. ROSS, N. L. BOWEN, H. G. FERGUSON, and M. I. GOLDMAN led a discussion on *The criteria of replacement.*

Dr. WILLIAM T. THOM, Jr., chief of the fuel section of the U. S. Geological Survey, has been appointed associate professor of geology at Princeton University, in effect at the fall term of 1927, and will give lecture and research courses on structural geology and petroleum and coal. He will continue geologic work for the Geological Survey during summer periods.